

From the results of these tests it seems quite probable that if similar tests could be conducted with a driver in the vehicle or a device to turn the wheels away from the guard at the moment of impact, which would be the natural condition if the accident were caused by skidding, highway guards made of heavy steel plates would act in an unusually successful manner.

From personal observation covering a period of years, it is the belief of the writer that the necessity for keeping the vehicle away from contact with the posts is very obvious, and it seems equally obvious that the most satisfactory results will be obtained from highway guard rail in which end anchorages are used, having sufficient rigidity to utilize the full strength of the guard rail throughout its entire length, rather than depend on the resistance of heavy posts.

The subject of guard rail design is attracting the attention of highway engineers and many improvements may be expected during the next few years. Some of the modern types of guard rail provide a reasonable degree of protection for the traveling public and there are other types which are now wholly inadequate due to the increase in speed of motor vehicle traffic.

## STABILIZATION OF GRAVEL ROADS BY USE OF CALCIUM CHLORIDE

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Grand Traverse County is located in the northwestern corner of Michigan, in the center of the summer resort region. Because of this fact, our roads, in summer, carry from two to three times the normal traffic. The type of people involved in this summer traffic expect and demand a smooth, dustless road surface.

It has taxed our resources to the limit to maintain such a standard on gravel roads under summer traffic conditions. The county now maintains approximately 350 miles of this type. Because of the sandy nature of the material which is locally available, these have been covered usually with loose gravel, and have required blading several times a week during the summer months in order to give even reasonable service to the traveling public. Such frequent maintenance has been expensive; yet replacement by a hard surface type has been out of the question because of the large investment of funds necessary. We have been eager, therefore, to find a type of surface which could be built at reasonable cost and which would remain smooth and dustless with low maintenance costs.

When the new stabilized gravel type of surface was called

to our attention, we made a trip to Midland County, Michigan, and inspected several experimental roads of this type. I must confess that we began the inspection in a doubting frame of mind; but after studying the theories involved in the stabilization of loose gravel by the addition of clay and subsequent application of calcium chloride, and after seeing the results that were being obtained, we were convinced that this type of improvement was well worth trying.

#### GENERAL DISCUSSION OF GRAVEL STABILIZATION

Before describing the gravel stabilization work which has been done in Grand Traverse County, it might be well to review briefly the definitions, theories, and facts that have served as the foundations upon which the field work has developed. Stability as applied to traffic-bound road surfaces is defined as resistance to lateral flow when loaded. Dry sand and wet clay are both unstable. Damp sand and dry clay, however, are stable. Loose gravel is unstable when it is dry and is likely to be so when it is wet. It is logical to expect, therefore, that some combination of these materials would give a satisfactory degree of stability under both wet and dry conditions.

The service properties of a gravel, limestone, or clay road depend chiefly upon the characteristics of the finer constituents of the wearing course. Soil mortar is the term usually applied to that portion passing a No. 10 sieve of the U. S. Standard Series. The proportion of soil mortar to coarse road metal is undoubtedly of importance, but if there is a sufficient quantity of the fine materials present and if these latter are stable, the road surface will be a very satisfactory one.

The degree of stability of a soil depends on the presence of two of the basic properties of soils, internal friction and cohesion. Internal friction is the resistance of soil grains to sliding over one another. It is furnished by sharp stones, gravel, sand, and silt. Cohesion is the stickiness of soil grains, or their resistance to being pulled apart. Cohesion is frequently subdivided into "true cohesion," which is supplied by clay, and "moisture-film cohesion," which is provided by thin films of water surrounding the soil particles. Compaction increases all cohesion, and calcium chloride provides moisture cohesion, particularly in dry weather.

The various soil constituents which are involved in the stabilization of gravel type roads, together with their properties and functions, are listed in Table I. The particle-size classification is that of the U. S. Bureau of Public Roads with the exception of the sieve-size between coarse and fine sands. Since the standard physical soil tests are performed on materials passing the No. 40 sieve, it has been found more convenient to consider that as the sieve for separating the coarse and fine sands rather than the No. 60 sieve which is used by the Bureau of Public Roads.

TABLE I  
COMMON SOIL CONSTITUENTS OF TRAFFIC-BOUND ROADS

Material	Particle Size Dia. Inches	Limiting Sieve Sizes*	Properties and Functions
Gravel or Coarse Material	Over .08	On No. 10	Supply internal friction to stable mixtures
Coarse Sand	.08 to .0165	Nos. 10-40	Alone, they have: High internal friction Little or no capillarity
Fine Sand	.0165 to .002	Nos. 40-270	No cohesion No compressibility or elas- ticity (hence are non- expansive)
Silt	.002 to .0002		Supplies internal friction to stable mixtures Alone, it has: Some internal friction Rapid capillarity (detrimental) No cohesion Compressibility (hence is expansive)
Clay	Under .0002		Supplies cohesion to stable mixtures Alone, it has: No internal friction Slow capillarity High cohesion Compressibility (hence is expansive)

\*U. S. Standard Sieve Series.

A stabilized gravel may be considered analogous to concrete. Both are composed of coarse aggregate which is surrounded and held in place by a mortar consisting of fine aggregate and a binding or cementing agent. In the case of concrete, portland cement is the binder. In the case of stabilized gravel, clay and moisture that is provided by calcium chloride furnish the cohesion for holding the fine and coarse aggregates in place. Silt, which is very fine in particle size, although coarser than clay, is undesirable in concrete. In stabilized gravel, it is beneficial when present in limited amounts, since it furnishes embedment for sand grains, thereby increasing the internal friction of the mass.

Clay expands when it becomes wet. For this reason, when it is present in a sand-gravel road mixture, the quantity of it should be such that maximum binding effect will be obtained without completely filling the voids. Then when the mixture becomes wet, the expansion of the clay particles may take place without unseating the silt and sand grains, which latter action would render the mixture unstable.

Simple soil tests, developed by the U. S. Bureau of Public Roads, make it possible to evaluate the binding properties of clay and thus aid in selection of the most suitable source of this material for a stabilization project. The same tests also make it possible to determine the proper proportions of the cohesive and frictional materials which must be present in order to provide a road surface which will have the most satisfactory properties.

The calcium chloride which is applied to the surface of the road dissolves in moisture which it attracts to itself either from the atmosphere or the road, or both. In dry weather, most of the calcium chloride solution is in the top half inch of the wearing course, where it keeps the road dustless and provides moisture cohesion for binding the soil particles in place.

When rain occurs, the calcium chloride solution is diluted and penetrates by gravity and capillarity down into the road for an inch or two. As the rain continues, the expansion of the clay particles tends to seal off the surface of the road so that more and more water is shed off into the ditches.

After the rain has ceased and drying takes place, the diluted calcium chloride solution is drawn to the surface by capillarity, where it is concentrated until it becomes an appreciably stronger solution. In this condition it functions in dry weather as previously described.

Our first project was undertaken on two miles of loose gravel road during the month of October, 1932. The excellent condition of this road during the spring months which followed convinced us of the merits of the stabilization methods and a number of other jobs were undertaken during 1933.

#### GENERAL PROCEDURE OF GRAVEL STABILIZATION

While the steps needed to complete a stabilized gravel road are not difficult for the experienced road man, each detail must be carefully followed, because any attempt to short-cut is likely to result in an unsatisfactory job.

*Drainage.* In common with any type of surface, a stabilized gravel road requires proper drainage so as to remove rainfall quickly from the surface and the subgrade. Side ditches must be provided, and in some cases tile under-drains are desirable.

*Sampling.* The road gravel on each of the projects was sampled at sufficient intervals to indicate the grading and

uniformity of the material. At each sampling station, holes were dug into the road on the center line and about 5 feet each side of the center. Ordinarily these holes were dug to a depth of 3 inches, and the materials from the three points at each station were assembled into a composite sample which was used in the laboratory tests. Samples of clay deposits in various parts of the county were also obtained. These were tested in order to indicate the best quality of binder material and to locate the most economically situated sources for use on the roads.

*Laboratory Tests.* All the roads which have been stabilized thus far have originally lacked cohesive material. While clay is well distributed in the county, most of the road grades and gravel pits are sandy. Tests involving those portions of the gravel samples which passed the No. 40 sieve and the similar fractions of nearby clays were made in the laboratory. The results were used to determine the proportion of clay which should be incorporated with the gravel on each job in order to provide a stable wearing course. In general, it was attempted to provide for a 3-inch mat which would have a plasticity index\* between 5 and 10. The laboratory reports indicated the quantities of definite clays which should be delivered per 100 feet of each road which was being stabilized.

*Clay Delivery.* The clay was dug from the pits with a power shovel and hauled to the jobs in 1½ cubic yard dump



Fig. 1. Digging clay from pit.

\* The plasticity index of a soil mixture is a measure of its binding power. For further information on the subject, consult *Reports on Subgrade Soil Studies*, U. S. Bureau of Public Roads, 1931, or *Improved Low Cost Soil and Gravel Roads*, the Dow Chemical Company, 1933.

trucks. Figure 1 shows the digging of clay for the Acme-Kalkaska County line job. Before the clay was spread, the loose gravel was bladed to the center of the road and the clay was deposited thereon. The loose material under the clay prevented the latter from sticking to the road. If the clay was reasonably dry as it came from the pit, it was immediately broken up by running a gravel roller over it, followed by a spring-tooth harrow. This accelerated the removal of the remainder of the moisture from the clay and also aided in crushing it. A view of loose clay on the Garfield Road is shown in



Fig. 2. Loose clay on center of road.



Fig. 3. Crushing clay with gravel roller.



Fig. 4. Loose clay after partial crushing.

Figure 2. The crushing procedure with the roller is shown in Figure 3, while clay after this operation appears in Figure 4.

When the clay, as delivered on the job, was too damp for immediate crushing as described above, it was bladed, together with the loose gravel, into windrows on each side of the road. There, drying took place, after which the mixture was returned to the road for crushing by the roller. Motor graders and truck blades were also used to work the clay and loose



Fig. 5. Blading loose gravel and clay to shoulders.



Fig. 6. Windrows of clay and gravel on shoulders.

gravel back and forth on the road surface to aid in drying and pulverizing it. When this was accomplished, the mixture was bladed into windrows on the shoulders to await the next operation. The blading of the mixture of loose gravel and clay to the shoulders is shown in Figure 5 and the resulting windrows appear in Figure 6.

*Scarifying.* The mixture of dry, pulverized clay and loose material was bladed uniformly over the surface of the road. This was followed by scarifying to the desired depth, which was usually sufficient to give a total of 4 inches of loose material, or 3 inches when compacted. A York rake, pulled by a 5-ton truck, was used in scarifying some of the jobs, while a motor grader, with a 20 horsepower caterpillar tractor aiding it, was used on others.

*Mixing and Removal of Oversized Stones.* After the old compacted road surface had been loosened to the desired depth, the York rake was again drawn over the road, using both the blades and the rake to mix the loose materials. The motor grader was next used to split the mixture of clay and scarified material out from the center of the road and to blade it back and forth, making sure that the mixture was turned over completely several times. This thoroughly mixed the fine and coarse constituents and also improved the cross-section of the road. A multiple blade maintainer is also used for mixing.

When the old road contained an appreciable quantity of oversized stones, an extra trip or two of the York rake after the mixing operation served to bring them to the side of the road. Following this operation, on some projects, the motor grader made a trip on the sides with the outer end of the blade raised. This assisted very much in delivering the large



stones to the shoulders, from which they were forked into trucks and hauled away.

*Shaping and Compacting.* On all but the last project, it was customary to shape up the finished mixture to a crown of  $\frac{1}{2}$  to  $\frac{3}{4}$  inch per foot and then to treat with calcium chloride. This latter operation was done during the late afternoon of the day on which the mixing was completed or early the next morning. The calcium chloride would attract moisture and thus aid in compacting the road as well as making it dustless. On some of the jobs, however, where there were several inches of loose material, a very damp crust would remain soft and unstable until after a rain occurred. This made it difficult to obtain a smooth and satisfactorily shaped road until some time after the construction work was completed.

This trouble was completely eliminated on the last two projects by introducing water from a sprinkling wagon during the shaping and compacting processes. All the loose material was windrowed to the sides of the road and the old compacted base was dampened with water. About one-fourth of the loose mixture on the shoulders was then immediately bladed over the whole road surface. Subsequent applications of water were made, followed in each case by layers of loose mixture until the latter was all on the road. The desired crown of the road was gradually built up as the sand-clay-gravel mixture was brought in from the shoulders. Traffic, of course, assisted in compacting the road. On the following morning, the road was again sprinkled and shaped. In this final shaping, the blade on the truck was set with very light pressure and the truck was operated at a relatively fast speed. This left the surface of the road in the best possible condition and calcium chloride was then applied at the rate of 2 or 3 tons per mile.

The procedure just described, of intermittently applying water to the mixture of sand, clay, and gravel as the materials were bladed onto the road for final compaction, was found to be the best method for the final stage of the stabilization process. By adding the water, first at the bottom and then to succeeding layers, a firm, finished road was immediately produced. Even when a heavy rain occurred a few hours after a section of road had been completed by this method, no appreciable softening of the road took place, as the water was shed almost completely.

#### COST DATA

An itemized account of costs was kept for each project and is listed in Table 2.

TABLE II  
STABILIZATION COSTS PER MILE OF GRAVEL ROAD  
GRAND TRAVERSE COUNTY, MICHIGAN

	Garfield 2 mi.	County Line 3 mi.	Acme- Kalkaska 8.63 mi.	Silver Lake 5.5 mi.	Secore 2 mi.	Average
Clay, in pit (10c per cu. yd.).....	15.60	9.00	18.80	26.00	28.60	22.25*
Loading Clay.....	46.85	12.55	22.40	36.25	34.44	34.98*
Hauling Clay.....	98.40	20.73	57.60	65.70	57.90	69.90*
Spreading Clay.....	12.15	8.15	10.10	16.50	9.73	12.12*
Pulverizing Clay.....	11.10	10.76	7.82	12.20	10.50	10.48
Scarifying, Mixing and Shaping.....	62.52	33.86	24.00	53.10	41.06	42.91
Stone Removal.....				8.60	36.45	.....
Sprinkling.....				33.00	34.10	33.55
Calcium Chloride (Applied).....		58.51	46.30	44.20	48.75	49.44
Total.....	246.62	153.56	187.02	295.55	301.53	275.63†

\*Costs from County Line project omitted because thickness of stabilized course was only 1.5 inches; other projects were 3 inches.

†Average, exclusive of cost of removal of stone. Width of stabilized wearing course was 20 feet on all projects.

In addition to the foregoing cost data and the general methods of carrying on the stabilization work in Grand Traverse County, the individual conditions peculiar to the various projects are of interest. These are discussed in the paragraphs which follow.

#### GRAVEL STABILIZATION PROJECTS

*Garfield Road.* This road was two miles south of the city limits of Traverse City and was the first stabilization project which was undertaken. The work was begun about the middle of October, 1932, and carried over into early November. Clay was delivered onto the road at the rate of 156 cubic yards per mile. This was sufficient for a 20-foot width of road scarified to a depth of 3 inches.

A great deal of wet weather was encountered during the work on this project. When the south mile had been partly scarified, a very heavy rain commenced. The scarifying was completed, however, and the mixing was done during the rain. Naturally, the road became quite muddy. The next morning,

after the rain had stopped, the road was further mixed with a spring-tooth harrow and truck blade. After about two hours, the road became so firm that work with the harrow was discontinued. The final shaping was done with the truck blade aided by the compaction which was furnished by traffic. Before any calcium chloride could be applied, another hard rain occurred, but it had very little effect on the finished road.

On the north mile, a great deal of difficulty was encountered in drying the clay, because of several rains and snowstorms. After several attempts, however, the clay was finally dried and pulverized, the road was scarified, and the materials were thoroughly dry-and wet-mixed. In fact, because of so much rain, it was necessary to remove the wet mixture to the shoulders and make no attempt to do any more with it for several days. Finally most of the mixture was dried out and put down in place, although a small part of it had to remain on the shoulders until spring.

In the fall of the year, there was some adverse criticism of the work because of the muddiness. In the spring this two-mile stretch was the best piece of gravel road in the county; and if there was any criticism, then it was that we hadn't stabilized a greater mileage. It is to be admitted, however, that late October and November is too late in the season for this type of work in our section of the country. It would be safe to say that the work could have been accomplished for about \$200 per mile earlier in the season, when costly delays due to cold wet weather would not have occurred. It should be noted that no calcium chloride was applied to the road until the next spring. Right up until winter set in, the surface was so continuously damp that the calcium chloride treatment was not warranted.

*County Line Road No. 612.* This three-mile project is a road for which plans had already been made to provide a tar-bound macadam surface. Owing to curtailment of expenses, however, it was decided to postpone the laying of the more expensive surface and to stabilize the existing gravel for a width of 20 feet and a depth of only 1½ inches. Laboratory tests indicated that this would require 90 cubic yards of clay per mile.

This project was begun June 24, 1933, and was finished five days later. After the dry mixing and shaping operations were completed, the dust nuisance was so great that the calcium chloride was applied at the rate of 2½ tons per mile. At this time, the improved method of using the sprinkling wagon to dampen and aid the compaction of the mixture had not been developed.

In this particular case, the calcium chloride was applied in the afternoon, and it soon reduced the dust nuisance. During the night, a heavy rain fell, but in the morning the road

was damp and well compacted, except in a few spots where the crown was somewhat low. In these latter places, the road was wetter and rougher. Subsequent blading put the road in good condition. A view of the County Line Road after the stabilization work was completed is shown in Figure 7.

*County Road No. 612 (Acme-Kalkaska).* This project, comprising 8.63 miles of gravel road, was started July 5, 1933, and completed on July 27. Extremely hot, dry weather prevailed during the entire time. Clay was used from two pits, one near to each end of the job. In one case, it required 247 cu. yds. of clay per mile of road to provide the desired cohesive properties to the finished road mixture, while in the other case,



Fig. 7. View of stabilized section of County-Line Road.

it required only 186 cu. yds. of clay per mile of road. The deposit of the better-quality clay was not as close to most of the project as the clay having the poorer binding properties. The cost of hauling, considering the quality and hence the amount of clay needed, was computed for each pit. These calculations showed us the proper point on the road to change from one pit to the other.

This job offered a good example of the need for moisture in the wearing course during the shaping and compacting processes. The finished mixture of clay, sand, and gravel was very dry and loose. The road was shaped in this condition and calcium chloride was applied to relieve the dust nuisance. Various sections of the project became rough in spots, however, until after they had been subjected to rainfall. This

was particularly true of the first mile over which clay for the rest of the section was hauled. A loose, shifting layer of sand-clay-gravel mixture existed under the surface layer after the latter was made damp with calcium chloride. Under such conditions, the traffic broke through the upper layer in many places and made ruts and rough spots. Following the first rain these loose areas became compacted and were smoothed with a truck blade.

*County Road No. 633 (Silver Lake).* Previous to stabilization, this road was covered with considerable loose gravel and was always hard to keep even reasonably smooth. Five and one-half miles of it were stabilized between July 28 and September 5, 1933. The quantity of clay used on this job was 260 cu. yds. per mile.

The operations on this project were the same as on the other jobs until, on the last section, a sprinkling wagon was used to dampen the mixed materials as they were shaped and compacted. The earlier sections of this road required one rainfall before they could be put in perfect condition, but by the time the last section was completed, the whole road was in very satisfactory shape and remained so with very little maintenance until the wet fall weather.

The mixing and scarifying costs on this job were somewhat high, because the work was done under summer traffic conditions and, in order to hasten its completion, three mixing units were employed. The cost of loading and hauling the clay was also abnormally high on this project because of the difficulty of access to the clay pit.

*Secore Road.* This project consisted of two miles of loose gravel road which had always been badly pitted during the summer months. It was stabilized between the 5th and 12th of September. The clay required by this job was 286 cu. yds. per mile, 20 feet wide.

#### MAINTENANCE

The amount, and hence the cost, of maintenance for stabilized gravel roads is much less than for the ordinary type. It is very important, however, that stabilized gravel be maintained at the proper time. Skill and experience in these operations are also very necessary.

Ordinary maintenance consists of patching, blading, and light applications of calcium chloride. After long intervals of dry weather, pit holes are liable to develop, particularly if the calcium chloride treatment has been delayed too long. These are patched with a mixture of clay, gravel, and calcium chloride, as near like the original preparation as possible. Gravel passing a  $\frac{1}{2}$  inch screen is preferred for this purpose. The pit hole is wet from an ordinary sprinkling can, the mixture is tamped into the hole with a shovel and leveled with the

surrounding surface, and then a light layer of calcium chloride is sprinkled over the patch.

Blading can be done only after a rain because in dry weather a blade will not cut the surface. Truck blades and motor graders are used for this purpose. Experience will teach the operator just the proper time after a rain to begin blading. Working too early will result in tearing the surface, while if the shaping is started too late, the surface will begin to harden and cannot be cut.

During the first season, slippery spots may develop after a hard rain, because it is difficult to maintain laboratory proportions of clay, sand, and gravel in the field. A light coat of pea gravel or coarse sand sprinkled over the places will correct this condition.

Our maintenance costs are kept by sections. Since our Acme-Williamsburg road was the only project where a complete maintenance section was stabilized, it is the only project where our costs can be compared with the costs on the original road. On this section, we were compelled to blade the old gravel six times a week during July and August. After stabilization, the road was kept in much better condition and required blading only seven times in July and four times in August.

#### CONCLUSION

Because we believe that stabilized gravel is the answer to many problems on our low-cost roads, our plans for the coming season call for the construction of 20 miles of this type. The economy which is effected by this type of road lies chiefly in two directions: first, the scraping maintenance is less; and second, the loss of materials from the road, and hence the quantity of replacement gravel is reduced considerably.

Another advantage of stabilization is the increased benefit that is obtained from the use of calcium chloride on surfaces of this type. By using three or four light treatments ranging from one to two tons per mile each, continuous dustlessness can be secured throughout the season at a low cost.

The low original cost of the stabilized gravel road must also be taken into consideration. This makes it possible, with a limited budget for new work, to give more miles of firm, dustless, and completely satisfactory surfaces to automobile owners of our county than we could ever hope to do by building the more costly pavement type of roads.